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Determination of Mental Workload During Operation of Multiple Unmanned Systems

by Regina A. Pomranky and Josephine Q. Wojciechowski

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NOTICES

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14. ABSTRACT

Many systems are being developed as part of the Army's Future Combat Systems (FCS). To determine the most effective and efficient way to integrate these new systems within the future force, the U.S. Army Research Laboratory's Human Research and Engineering Directorate is using predictive modeling to analyze the workload of FCS operations. This analysis is part of the Robotics Collaboration Army Technology Objective in which Soldier workload models of individual systems are being developed with the intent to be integrated into one complex model. This model will enable the investigation of Soldier workload as well as how these Soldiers and systems can more effectively combine their efforts to accomplish a mission. The reported effort can be incorporated into the complex model. FCS-equipped brigade combat teams (BCTs) consist of a family of advanced, networked air- and ground-based maneuver, maneuver support, and sustainment systems that will include manned and unmanned platforms. The FCS BCTs will rely heavily on unmanned systems to enable the "quality of firsts" (see first, understand first, act first, and finish decisively) by performing such missions as reconnaissance, surveillance, target acquisition, security, and communications relay. The robotics non-commissioned officer duties within FCS BCT include operating multiple unmanned systems. Given the complexity of future operating environments, the operation of multiple unmanned systems will often occur simultaneously. The number of unmanned systems that a Soldier can effectively operate simultaneously is one area of concern in the fielding of these systems. Further, the level of autonomy required to concurrently operate multiple systems effectively will need to be determined. One system of interest is the Defense Advanced Research Project Agency micro-air vehicle (MAV) being developed under an advanced concept technology demonstration. This system is a surrogate that represents the future Class I unmanned aircraft system. To investigate the possible effects on performance of simultaneously operating multiple systems, a workload model was developed to examine performance while as many as three MAVs are operated. Results indicate that the workload for the operation of one MAV was well within the cognitive limits of a normal Soldier. Operation of two unmanned systems showed high levels of visual demand and very high levels of cognitive demand. Effectiveness at this level could depend on the level of autonomy and would present high probability of error. Effective operation of more than two unmanned systems at a time results in extremely high workload levels indicating a Soldier's inability to effectively or safely operate those systems, regardless of the autonomy of the systems.

15. SUBJECT TERMS
human performance; task and workload modeling; unmanned aerial vehicles

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1. Introduction

Many new systems are being developed as part of the Army's Future Combat Systems (FCS). To determine the most effective and efficient way to integrate these new systems within the future force, the U.S. Army Research Laboratory’s (ARL’s) Human Research and Engineering Directorate is using predictive modeling to analyze the workload of FCS operations. This analysis is part of the Robotics Collaboration Army Technology Objective in which Soldier workload models of individual systems are being developed with the intent to be integrated into one complex model. This model will enable the investigation of Soldier workload as well as how these Soldiers and systems can more effectively combine their efforts to accomplish a mission. FCS-equipped brigade combat teams (BCTs) consist of a family of advanced, networked air- and ground-based maneuver, maneuver support, and sustainment systems that will include manned and unmanned platforms. The FCS BCT will rely heavily on unmanned systems to enable the “quality of firsts” (see first, understand first, act first, and finish decisively) by performing such missions as reconnaissance, surveillance, target acquisition, security, and communications relay. In fact, at least 11 types of unmanned aerial vehicles (UAVs) were committed to Operation Iraqi Freedom, demonstrating the current need for the capabilities that UAVs can provide. The robotics non-commissioned officer duties within the FCS BCT include at least coordination of and possibly operation of multiple unmanned systems. Given the complexity of the future operating environment, the operation of multiple unmanned systems will often occur simultaneously. Questions to be addressed include (a) how many unmanned systems can a Soldier effectively operate simultaneously, and (b) what level of autonomy is required to concurrently operate multiple systems effectively? To investigate the possible effects on performance of simultaneously operating multiple systems, a workload model was developed to examine operator performance while as many as three micro-air vehicles (MAVs) were operated.

1.1 System Description

The FCS Class I surrogate system (MAV) is a lift-augmented ducted fan UAV capable of vertical take-off and landing. The MAV provides near real-time electro-optical (EO) or infrared (IR) full motion video to support situational awareness (SA) and understanding. It can accomplish unique military missions, particularly with regard to flight operations in restricted environments. The MAV system includes two air vehicles, camera sensors (one EO and one IR) an operator control unit (OCU), a ground data terminal, and associated ground support equipment. Figures 1 through 4 display the different components of the MAV. The OCU and its associated graphical user interface (GUI) will allow the operator to train, plan, program, execute, and record MAV missions. Operators will direct the air vehicle (AV) during the mission, as opposed to manually flying the AV by using a touch screen. Flexibility in the OCU and GUI is important and must allow an operator to dynamically re-task the AV (assume manual control) by touching the screen and

directing it to fly to the point or in the direction touched. The system will provide the small unit with militarily useful real-time combat information of difficult-to-observe or distant areas or objects. The system will also be employable in a variety of war-fighting environments (e.g., in complex topologies such as mountainous terrain, heavily forested areas, urban areas, confined spaces, and high concentrations of civilians). The initial MAV technology development program focused on the technologies and components required to enable flight at small scales, including flight control, power and propulsion, navigation and communications.

Figure 1. MAV.

Figure 2. MAV dismounted control unit.

Figure 3. Assembly of the MAV.

Figure 4. MAV in a backpack.

1.2 Purpose

The purpose of this study is to assess the extent to which MAV operators can simultaneously operate as many as three MAVs in varying modes of operation (manual and autonomous). We accomplished this by varying the number of MAVs and their mode of operation (manual and

autonomous) and by analyzing their associated workloads. These models of operator workload could lead to improved system design or crew configuration changes as well as the development of tactics, techniques, and procedures that may save the Army time, money, and resources.

2. Method

Modeling and simulation allow researchers to establish a relationship between events and behaviors while evaluating human performance without actually using human participants. In fact, a strength of modeling and simulation is the ability to conduct research on developmental systems such as those proposed for the FCS. The task analysis and modeling methodology used to determine the workload associated with operating multiple unmanned systems are described as follows. An analysis of MAV operator tasks was performed which resulted in a detailed task list. Modeling was then used to develop a graphical representation of the flow of tasks as well as the assignment of workload values for each task. Finally, the MAV model was executed to examine the workload associated with operating multiple unmanned systems.

2.1 Task Analysis

We performed a task analysis of the MAV by observing and interviewing subject matter experts (SMEs) and Soldiers operating the system during a functionality assessment. These SMEs were the Soldier Battle Lab[1] contractors of the system as well as two trained E-6s. All contractors and Soldiers completed a 40-hour operator training course of the system at Honeywell[2]. The completed task list consists of the tasks required to operate the MAV in manual and autonomous modes. Finally, participation in and observation of MAV functionality assessment occurred at Fort Benning, Georgia. These tasks are documented in appendix A.

The focus of this study was to examine tasks associated with flying the MAV; therefore, tasks for launching and landing the vehicle are not included. The operator performed three functions for each vehicle: manually adjusting the vehicle, monitoring video feedback from the vehicle, and monitoring the system status of the vehicle. Additionally, the operator performed communication tasks and received vibratory alerts. When the vehicle was operated in autonomous mode, the manual adjustment function was not performed. The task list in appendix A includes the functions, the tasks associated with each function, and the mean task time for each task.

2.2 Modeling Approach

ARL’s Human Research and Engineering Directorate has developed a modeling tool called the Improved Performance Research Integration Tool (IMPRINT Version 7) to assess task and

[1]Located at Fort Benning, Georgia
[2]Located at Albuquerque, New Mexico

workload demands and to evaluate human and system performance (IMPRINT, 2007). IMPRINT incorporates workload theory, which states that every task a human performs requires some demand on attentional resources. IMPRINT is used to assign values to the amount of effort used to perform a task (Mitchell, 2000).

The "goal-oriented" module of IMPRINT was used to analyze operator workload for the MAV. This allowed the analyst to use advanced modeling capabilities such as tactical branching and variables to execute conditions. Additionally, the goal-oriented module uses the visual, auditory, cognitive, and psychomotor (VACP) workload methodology. Goal orientation allows the mission to be analyzed (in this case, operating the MAV), to be described as a series of goals. A goal matrix is then developed to describe the interactions of the competing goals.

The workload methodology associated with goal orientation is called VACP. For each task that the operator performs, the modeler assigns workload in each of the four resource channels on a scale from 0 through 7. The workload scales are shown in appendix B. As tasks are completed, the demand on each resource is summed for all the tasks being simultaneously executed. One can then view the times when the workload score is more than 7 as periods of overload in that resource.

Additionally, the workload across the four resources is sometimes added to calculate an overall workload value. An overall summation of resource channels greater than 40 has been bench-marked as high workload (Mitchell, 2003; Mitchell et al., 2003; Wojciechowski et al., 2001; Wojciechowski, 2006). The sum of all resource channels at a maximum for a single task would be 28 (four channels at maximum of 7). A score of 40 indicates that more than one resource channel is well beyond the maximum of 7, meaning that several channels are overloaded in more than one task. For the purposes of this study, workload was considered overloaded if any one channel was greater than 7 or the summation of the four workload channels was greater than 40.

The tasks developed in the previously described task analysis section were modeled in IMPRINT to represent the tasks of operating the MAV aircraft. This consisted of three major functions for each MAV previously described. Also included were the two functions that the operator performs in conjunction with operating the aircraft, independent of the number of aircraft being operated: UAV communication and receiving vibratory alert.

Each of the functions was configured as a separate goal in the IMPRINT software. The goals were given priorities and the interaction between the goals was controlled by the goal action matrix. Figure 5 shows the goals in order of priority. The goal action matrix controls when tasks happen and for how long, based on priority. In this case, the objective was to determine the workload when all tasks are completed. The goal action matrix was set so that no tasks were interrupted or suspended. Therefore, the priority of the goals had no impact on the operation of these tasks.

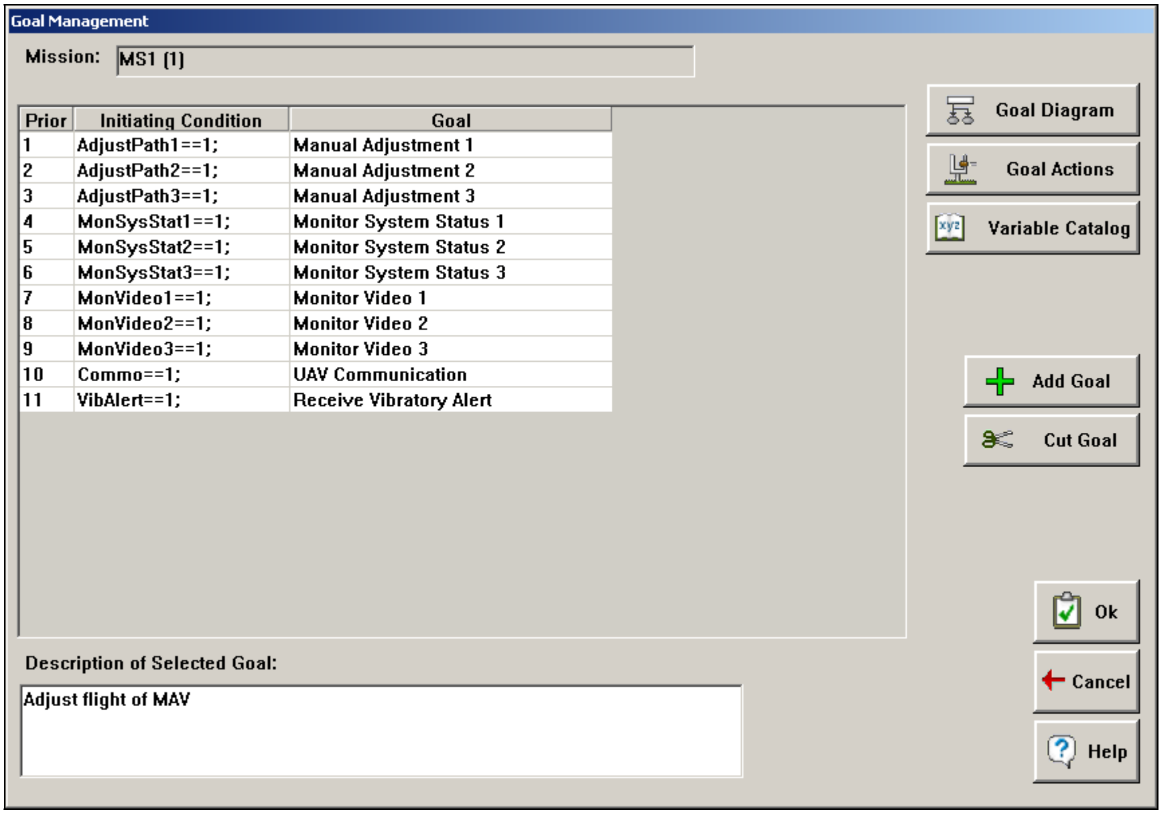

Figure 5. Goal management screen indicating goal priority.

The goals are triggered, based on three scenarios developed for operation of a MAV, which used a basic diamond configuration shown in figure 6. In the first mission, the MAV launches from the Home Waypoint (WP), proceeds to WP A and executes a “fly-by”. It then proceeds to WP B at which time, it circles or hovers over WP B. Finally, the AV follows a road heading toward WP C. Before reaching WP C, the AV receives a vibratory alert indicating low fuel at which point, the AV proceeds directly to the home WP and lands. Mission 2 used the same diamond configuration; however, the AV starts at the home WP and proceeds in a counter-clockwise direction toward WP C, bypassing WP C’s location and proceeding to the point the AV left the curvy road in Mission 1. The AV completes Mission 2 by following the curvy road to WP B, then to WP A and finally, back to the Home WP. In Mission 3, the AV launched from the home WP, climbed in altitude and hovered above the entire area of operation (AO). About three quarters of the way through the flight, a vibratory alert is given, indicating that additional surveillance is needed at WP A. The AV then proceeds to WP A, descends for a closer look, and then returns to the Home WP.

Although it may seem that workload would be the same for Scenarios 1 and 2 because they are the same scenario in reverse order, changing the order in which goals are triggered will alter the timing of specific tasks. This will give different workload peaks and transitions than are seen with Scenario 1.

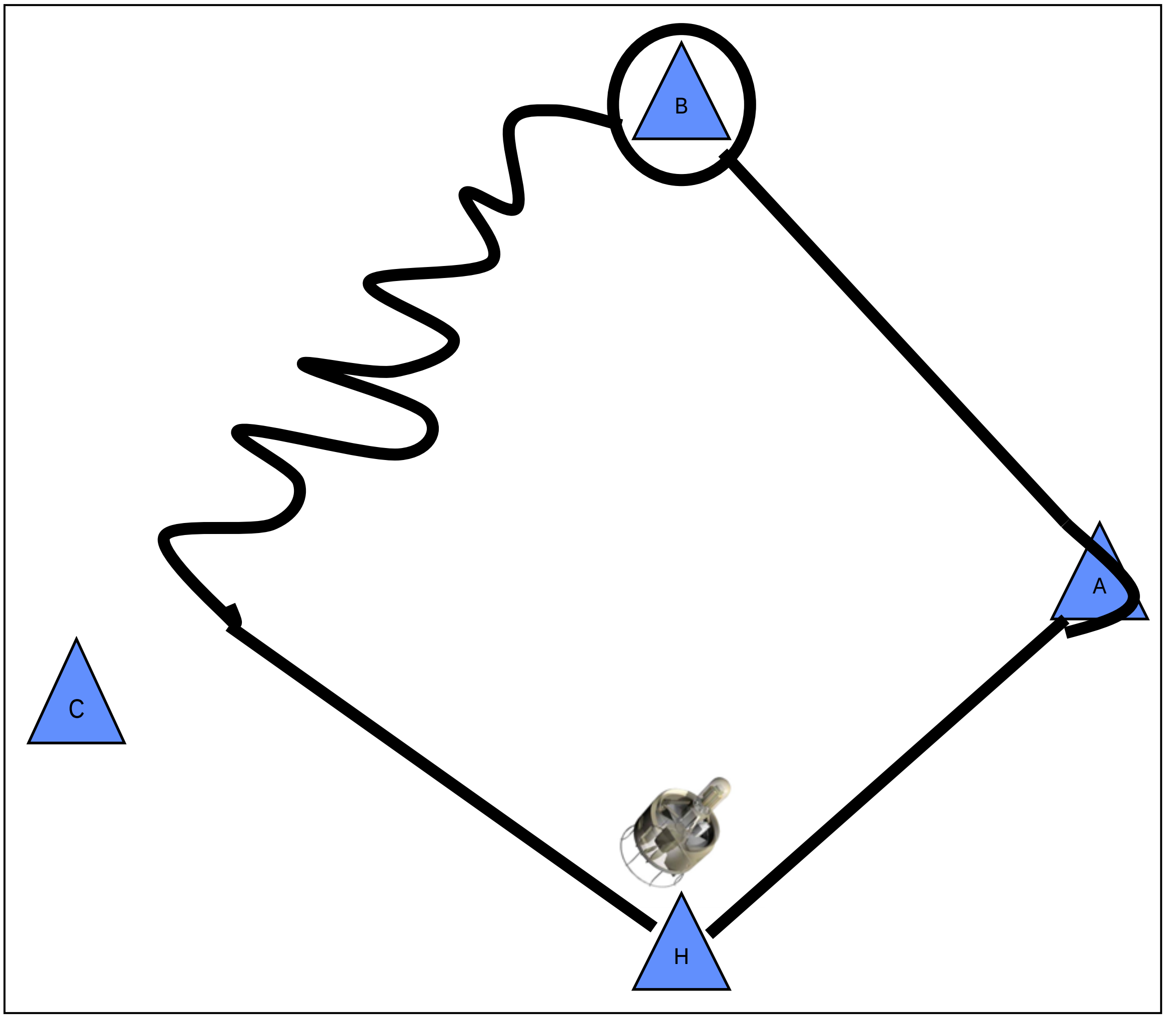

Figure 6. Basic diamond configuration scenario.

2.3 Experimental Design

2.3.1 Independent Variables

Two independent variables were used in this design. One was the number of manual MAVs that the operator was controlling and the other was the number of autonomous MAVs the operator was controlling. A minimum of one vehicle and a maximum of three were chosen for this investigation. This design led to nine possible combinations of MAVs in manual and automatic. Each of these combinations (shown in table 1) represented a condition tested in the model.

Table 1. Nine conditions modeled

Mode	No MAVs in Manual	One MAV in Manual	Two MAVs in Manual	Three MAVs in Manual
No MAVs in Autonomous		x	x	x
One MAV in Autonomous	x	x	x	
Two MAVs in Autonomous	x	x		
Three MAVs in Autonomous	x			

2.3.2 Dependent Variables

The percent time of the mission that the MAV operator is in mental demand overload was chosen as the dependent measure for this analysis. The mental demand is measured in the four resource channels: visual, auditory, cognitive, and psychomotor. The channels are added for an overall workload score and the percent time in overall workload was measured. For this experiment, the analysis focused on visual, cognitive, and overall demand because the tasks had very limited auditory and psychomotor demand. The three variables of interest are percent time the operator had visual demand greater than 7, the percent of time the operator had a cognitive demand greater than 7, and the percent of time that the operator had an overall workload demand greater than 40.

2.4 Procedure

Since three scenarios were available, all possible combinations of scenarios for each condition were tested in order to ensure that the results were not biased by the scenario chosen. The conditions tested were balanced in terms of scenario because the scenario was equally distributed in each condition. This eliminated the effect of scenario as a variable. Table 2 shows the list of the possible combinations. MS1AS2AS3 is equivalent to one MAV in manual flying scenario 1, one MAV in autonomous flying scenario 2, and one MAV in autonomous flying scenario 3. Fifty model runs were completed for each combination to ensure that the variability exhibited was from the model itself and not from the random number seed chosen.

2.5 Data Analysis

IMPRINT provides output files that summarize the workload changes over time. These files were manipulated via Excel[3] macros to calculate the percent time each model run was in overload as defined by visual demand over 7, cognitive demand over 7, and overall demand over 40. These data were analyzed with the Statistical Package for Social Sciences (SPSS)[4] to determine if statistical differences were present. The three dependent measures were analyzed with an analysis of variance (ANOVA). *Post hoc* analysis was completed with the Least Significant Difference (LSD) method. ANOVA tables are shown in appendix C.

Table 2. Twenty-six possible combinations of scenario representing each condition

Mode	No MAVs in Manual	One MAV in Manual	Two MAVs in Manual	Three MAVs in Manual
No MAVs in Autonomous		MS1, MS2, MS3	MS1MS2, MS1MS3, MS2MS3	MS1MS2MS3
One MAV in Autonomous	AS1, AS2, AS3	MS1AS2, MS1AS3, MS2AS3, MS2AS1, MS3AS1, MS3AS2	MS1MS2AS3, MS1AS2MS3 AS1MS2MS3	
Two MAVs in Autonomous	AS1AS2, AS1AS3, AS2AS3	MS1AS2AS3, AS1MS2AS3, AS1AS2MS3		
Three MAVs in Autonomous	AS1AS2AS3			

[3]Excel is a registered trademark of Microsoft Corporation.

[4]SPSS is a registered trademark of SPSS, Inc.

3. Results

3.1 Results by Condition

The visual workload channel is in overload when the workload level is greater than 7. Figure 7 shows the mean percent time in visual overload for each condition. The ANOVA indicates significant differences between conditions $F(8,441) = 8833$, $p < 0.001$. *Post hoc* analysis indicates different conditions as designated by the lower case letters on figure 7.

The cognitive workload channel is in overload when the single channel workload level is greater than 7. Figure 8 shows the mean percent time in cognitive overload for each condition. The ANOVA analysis indicates significant differences between conditions $F(8,441)=7303$, $p < 0.001$. *Post hoc* analysis indicates different conditions as designated by the lower case letters on the chart.

Overall workload is the sum of the VACP channels. Overall workload is considered in overload when its value is greater than 40. The mean percent time in overall workload for all conditions is given in figure 9. The ANOVA shows that significant differences between conditions are evident, $F(8,441)=1741$, $p < 0.001$. *Post hoc* analysis indicates that percent time in overall workload overload is approximately zero for any condition with one or two MAVs in operation. The conditions when three MAVs are in operation are significantly different from each other and all conditions when there are one or two MAVs.

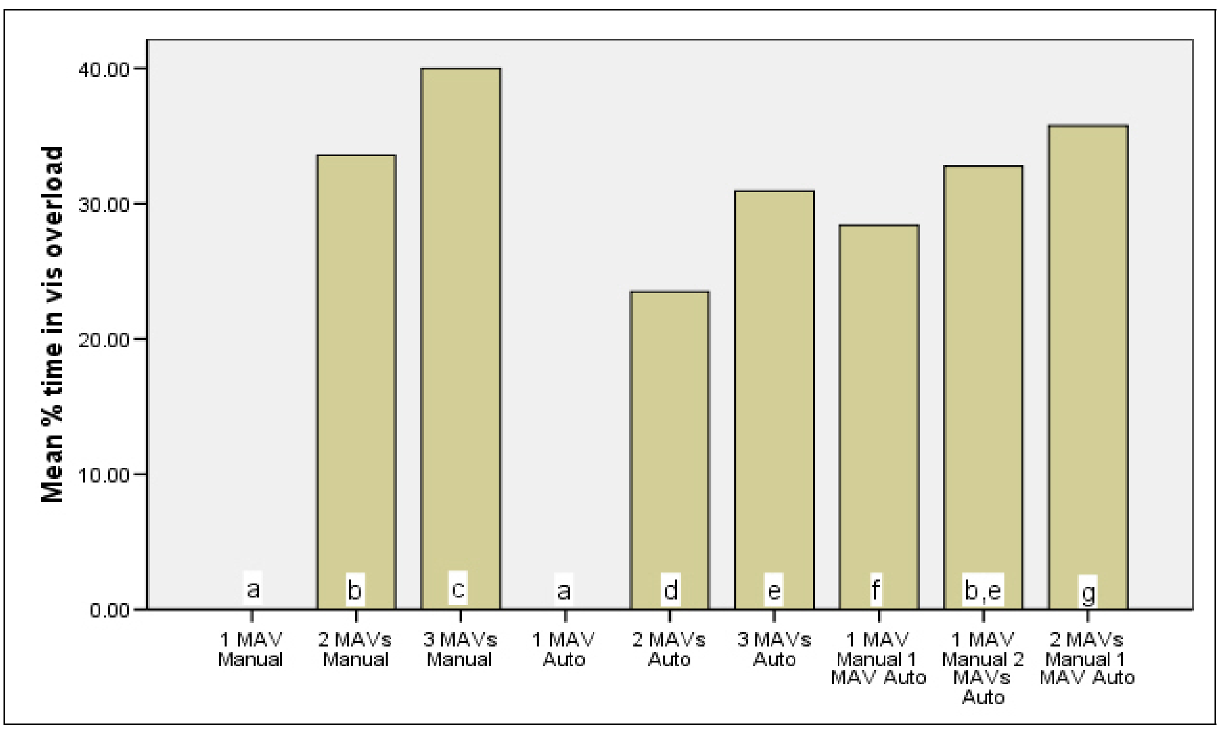

Figure 7. Percent time in visual overload (>7) by condition.

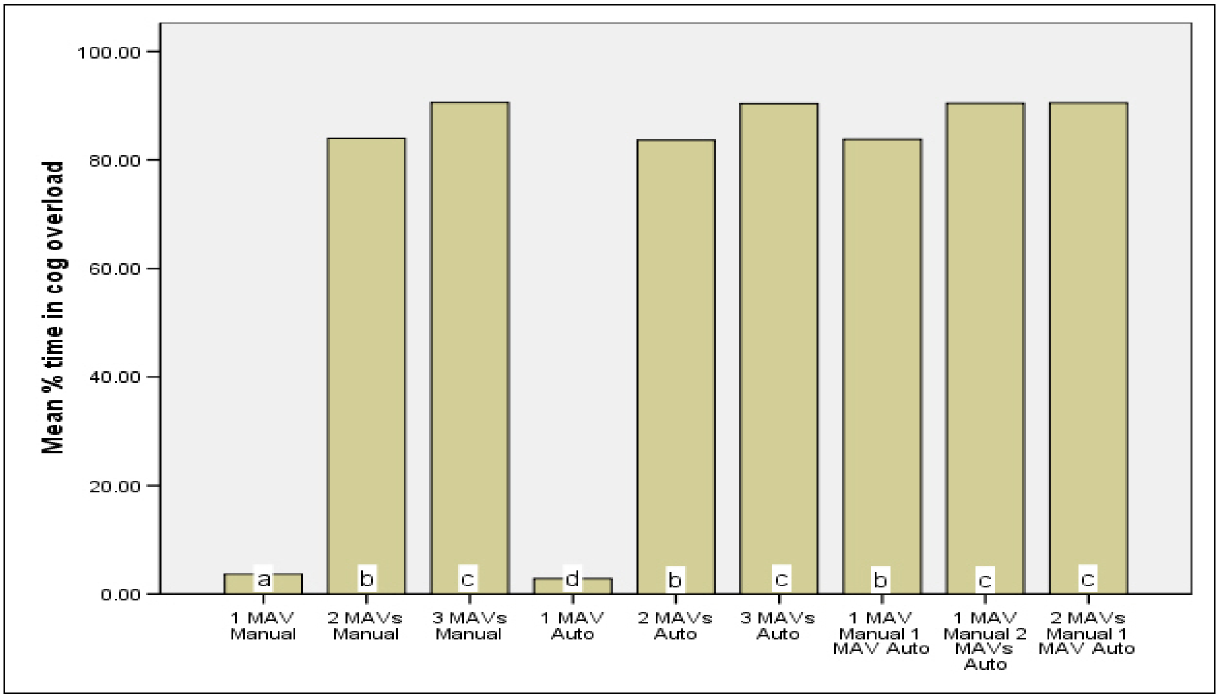

Figure 8. Percent time in cognitive overload (>7) by condition.

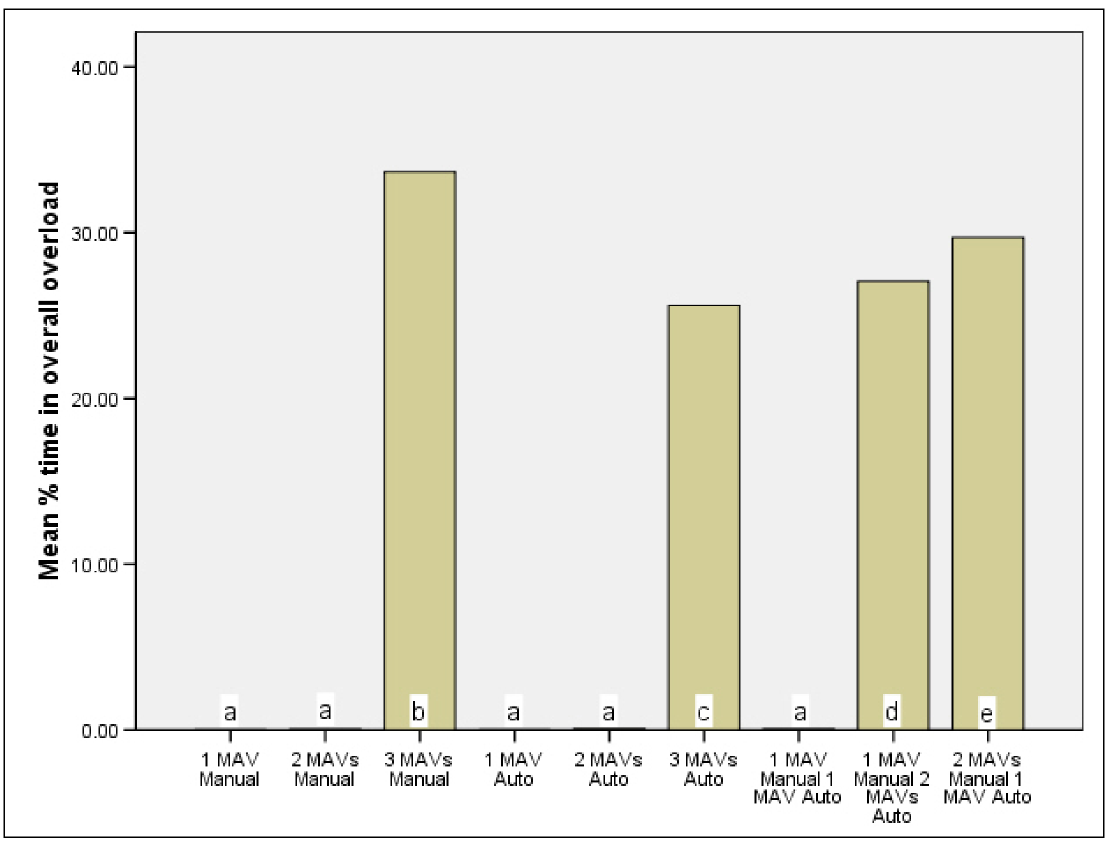

Figure 9. Percent time in overall overload (>40) by condition.

3.2 Results by Number of Vehicles

ANOVAs were also run on percent time in visual overload, based on the number of vehicles in operation. Significant differences were shown between the number of vehicles in operation $F(2,1297) = 2564$, $p < 0.001$. These data are presented in figure 10.

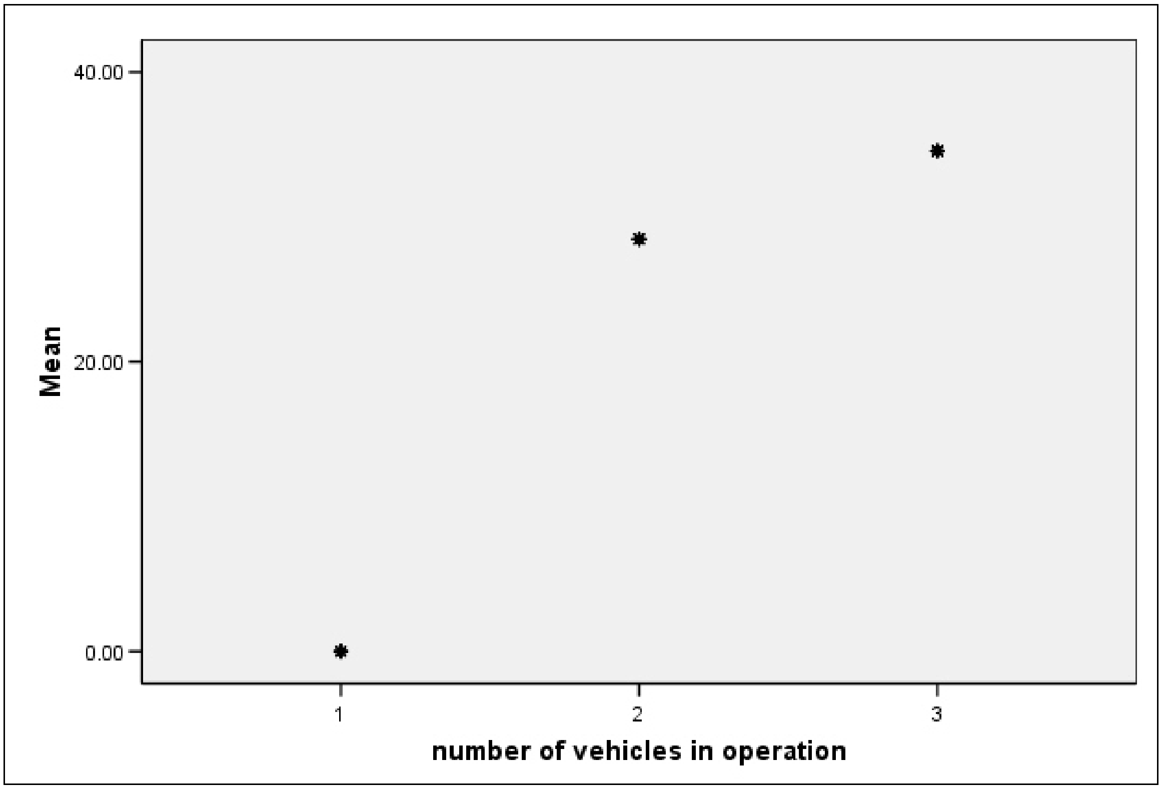

Figure 10. Percent time in visual overload (>7) by number of vehicles.

ANOVAs were also run on percent time in cognitive overload based on the number of vehicles in operation. Significant differences were shown between the number of vehicles in operation $F(2,1297) = 70806$, $p < 0.001$. These data are shown in figure 11.

Significant differences in overall overload are shown when just the number of vehicles is analyzed, $F(2,1297) = 16010$, $p < 0.001$. These data are shown in figure 12. As the figure illustrates, there are no difference in the percent of time in overall overload between conditions with one or two MAVs.

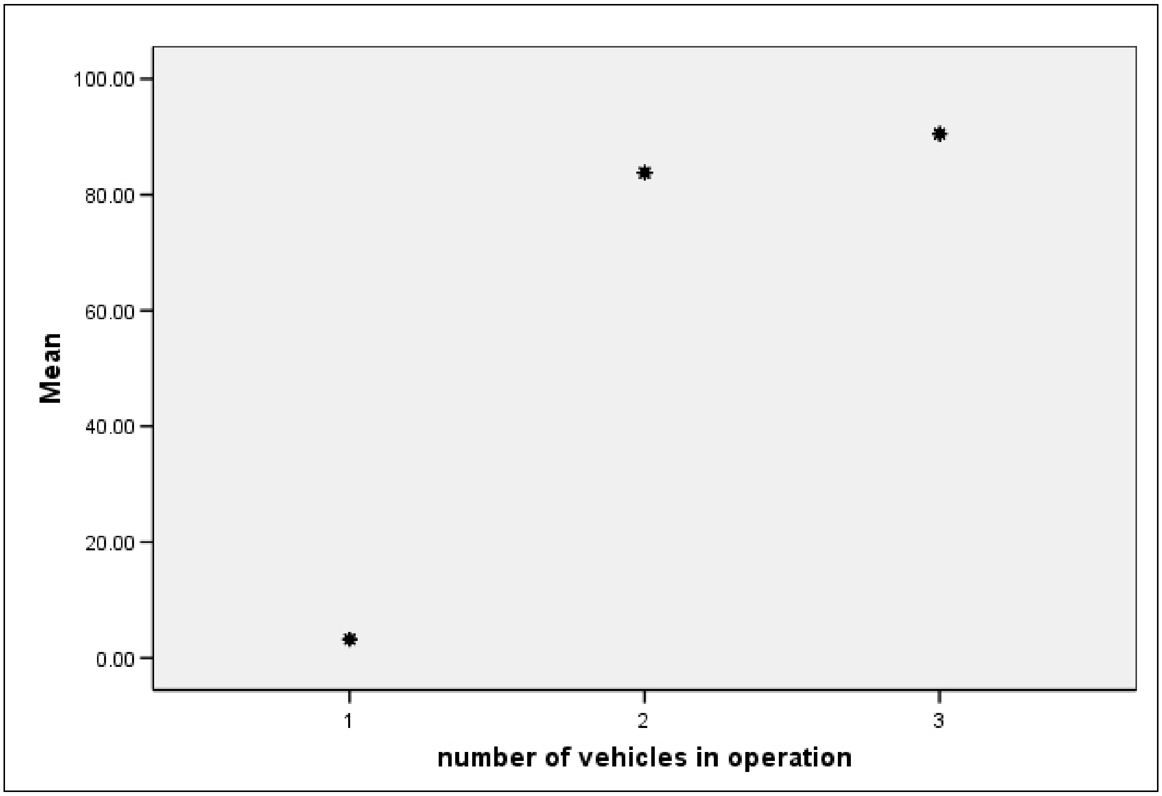

Figure 11. Percent time in cognitive overload (>7) by number of vehicles.

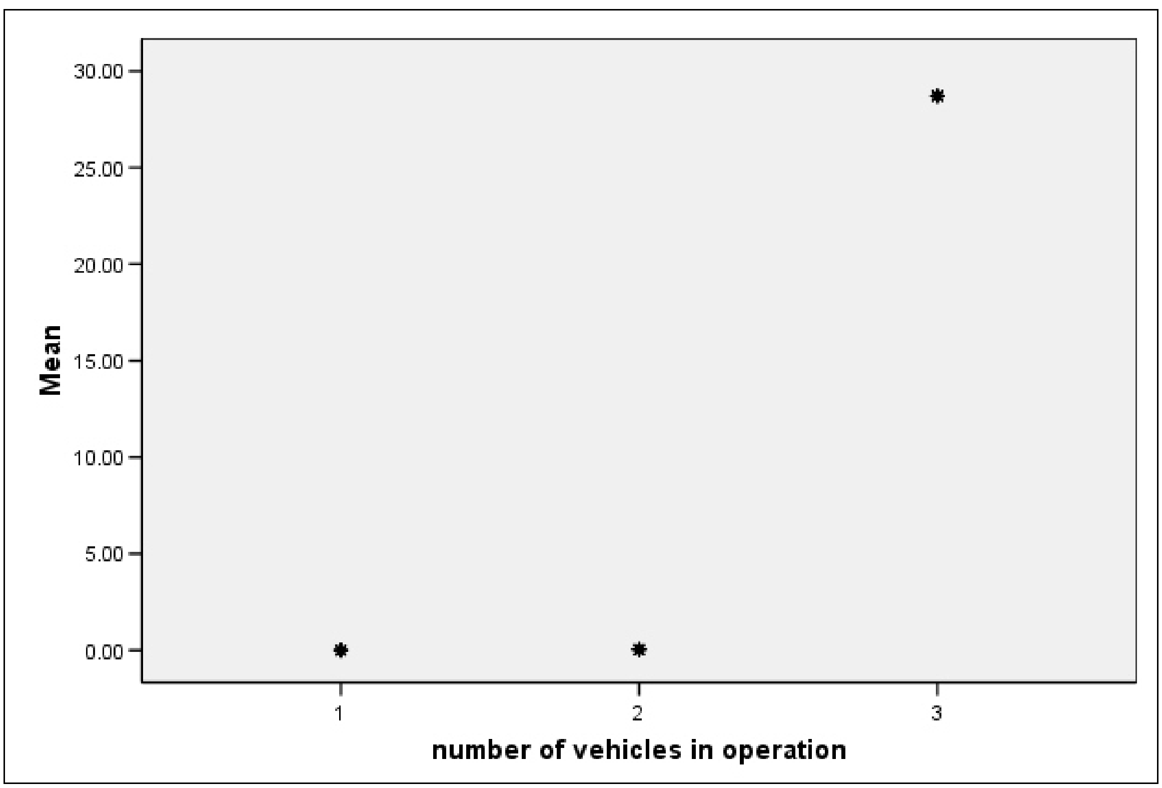

Figure 12. Percent time in overall overload (>40) by number of vehicles.

3.3 Results by Mode of Control

To determine the effect of mode of operation, conditions with equal number of vehicles were compared. An ANOVA was run on percent time in visual overload, based on the operation of a single vehicle, two vehicles, and three vehicles. When only a single vehicle was operated, there was no significant different in percent time in visual overload, based on operation in manual or autonomous mode, as shown in figure 13. When two MAVs were operated, there were significant differences whether the vehicles were in manual or autonomous mode, as shown in figure 14 ($F(2, 600) = 57.992$, $p < 0.001$). *Post hoc* analysis shows that all three combination of two vehicles are different from each other. When three vehicles were operated, there were significant differences for the mode of operation as shown in figure 14 ($F(3,400) = 45.669$, $p < 0.001$. *Post hoc* analysis indicates that all combinations of mode of operation are different from each other.

The same analysis was performed, comparing the percent time in cognitive overload. ANOVA results show that when a single MAV is operated, there are cognitive overload differences between operation in manual versus autonomous mode, as shown in figure 15 ($F(1,300) = 31.584$, $p < 0.001$. When two unmanned vehicles are operated, there are no significant differences in the mode of operation, as shown in figure 16. When three MAVs are operated, the mode of operation is significant as shown in figure 17 ($F(3,400) = 6.222$, $p < 0.001$. *Post hoc* analysis showed differences between all manual operation and one or no vehicles in manual. Two vehicles in manual are significantly different than no vehicles in manual.

Percent time in overall overload was also examined. ANOVA results show that operation of a single vehicle is not significant in terms of the mode of operation as shown in figure 18. The difference in the percent time in overall overload is significant when one is operating two vehicles, as shown in figure 19 ($F(2, 600) = 4.315$, $p = 0.014$. *Post hoc* analysis indicates that in terms of percent time in overall overload, operating both vehicles in manual mode is significantly different from operating both vehicles in autonomous mode, but neither is significantly different from operating one vehicle in manual and one in autonomous. The percent time in overall overload is significantly different in terms of mode of operation as shown in figure 20 ($F(3,400) = 43.322$, $p < 0.001$. *Post hoc* analysis shows that all combinations of mode of operation are significantly different from each other.

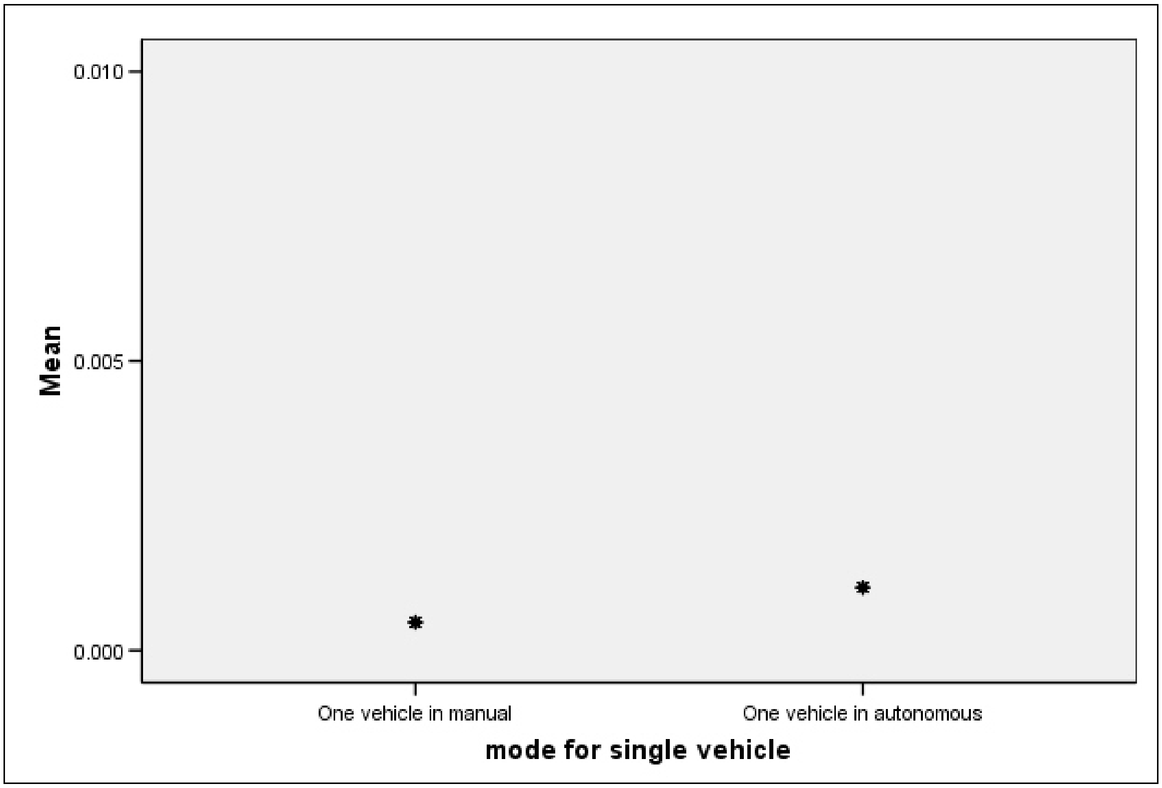

Figure 13. Percent time in visual overload by mode for one vehicle.

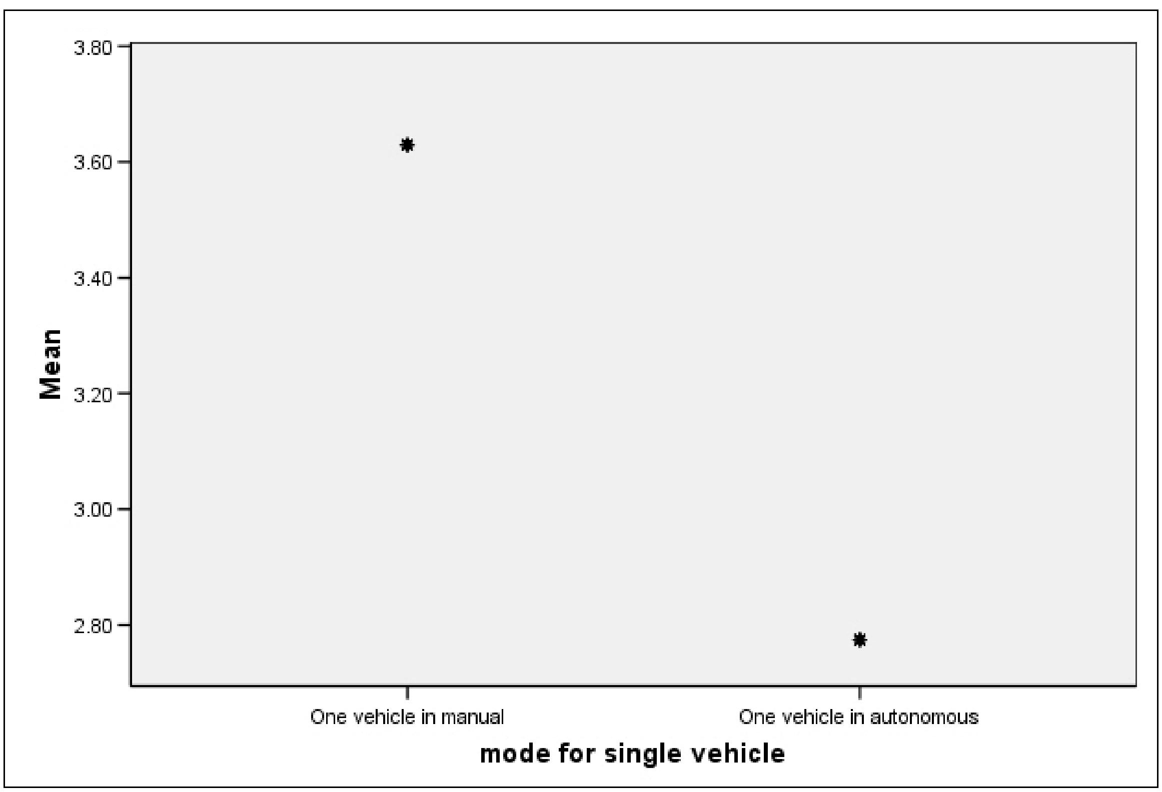

Figure 14. Percent time in cognitive overload by mode for one vehicle.

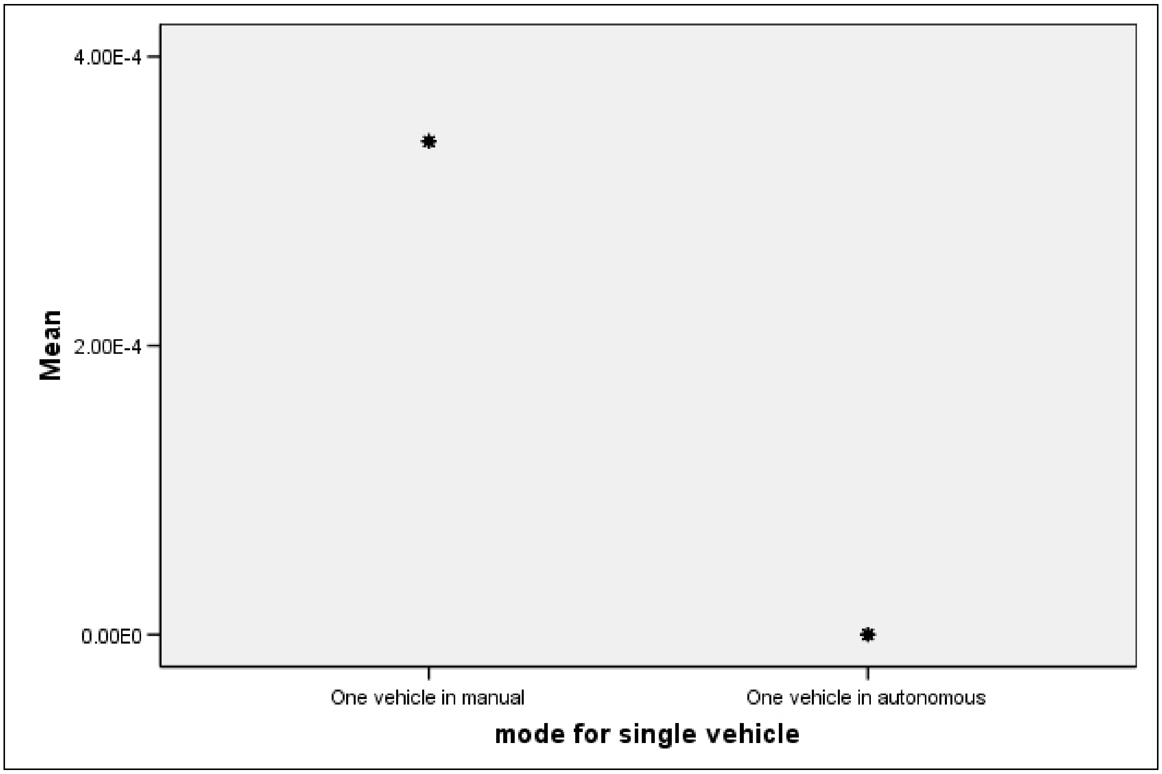

Figure 15. Percent time in overall overload by mode for one vehicle.

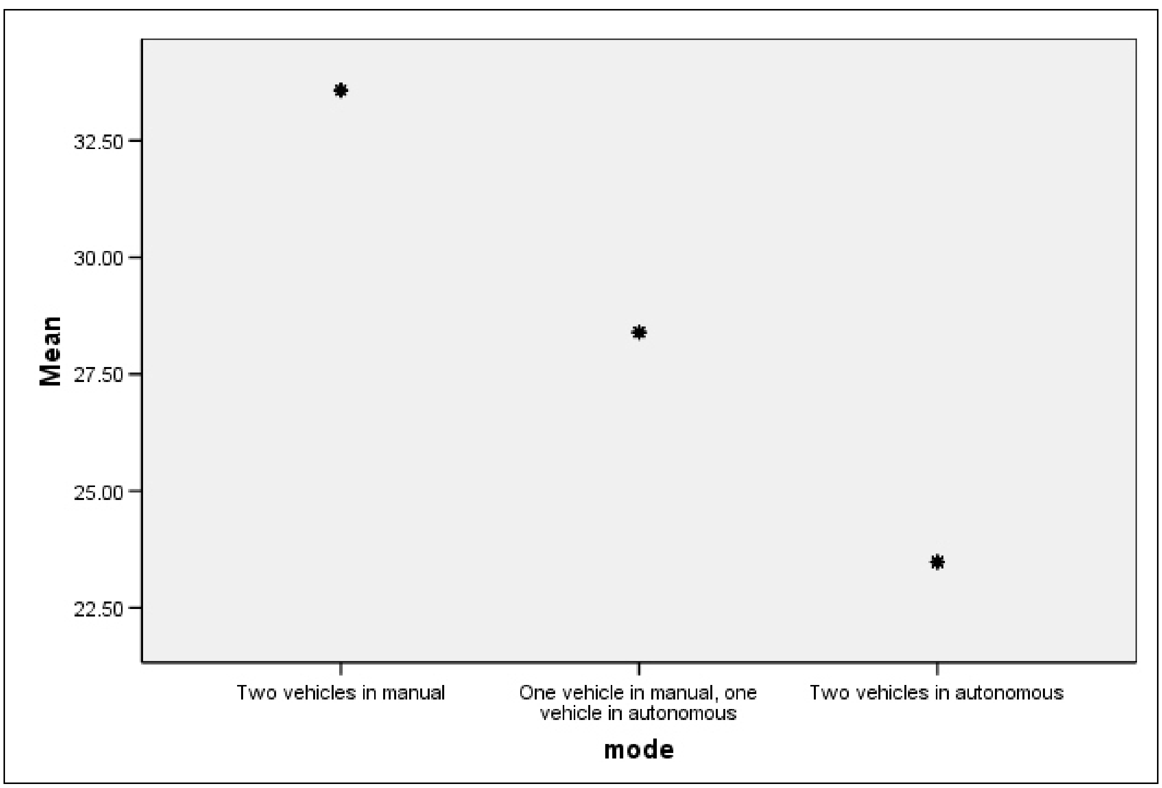

Figure 16. Percent time in visual overload by mode for two vehicles.

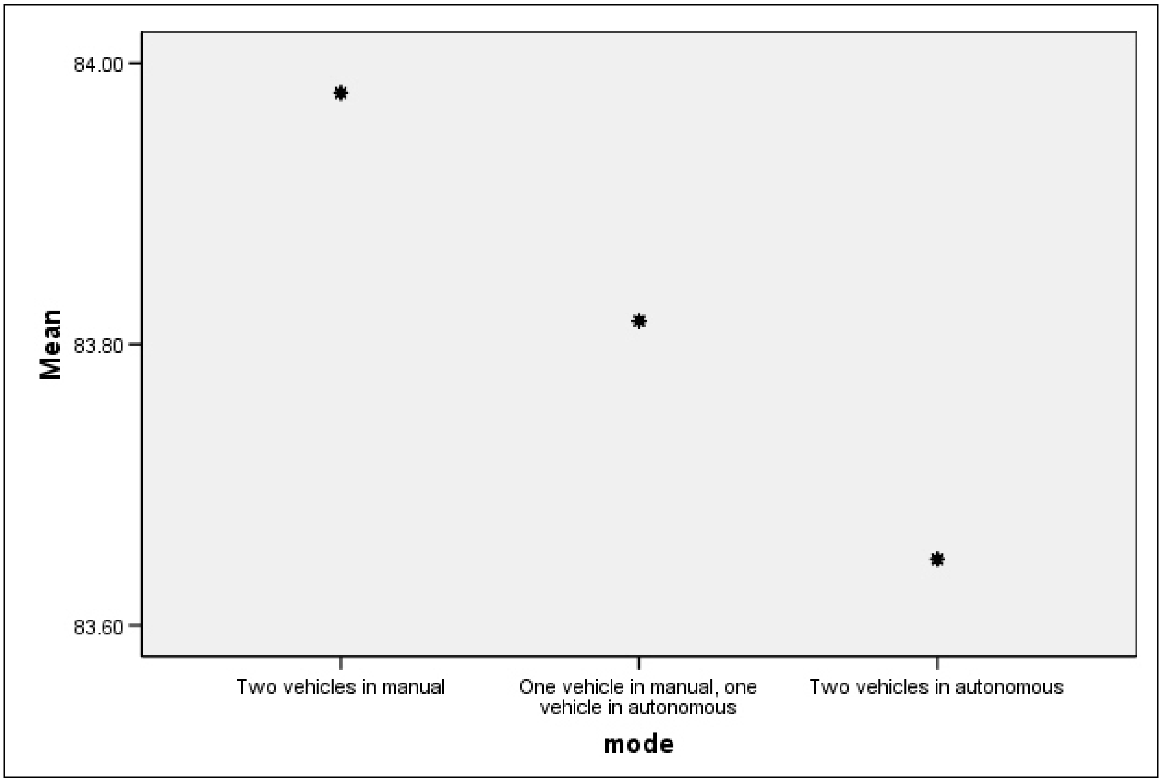

Figure 17. Percent time in cognitive overload by mode for two vehicles.

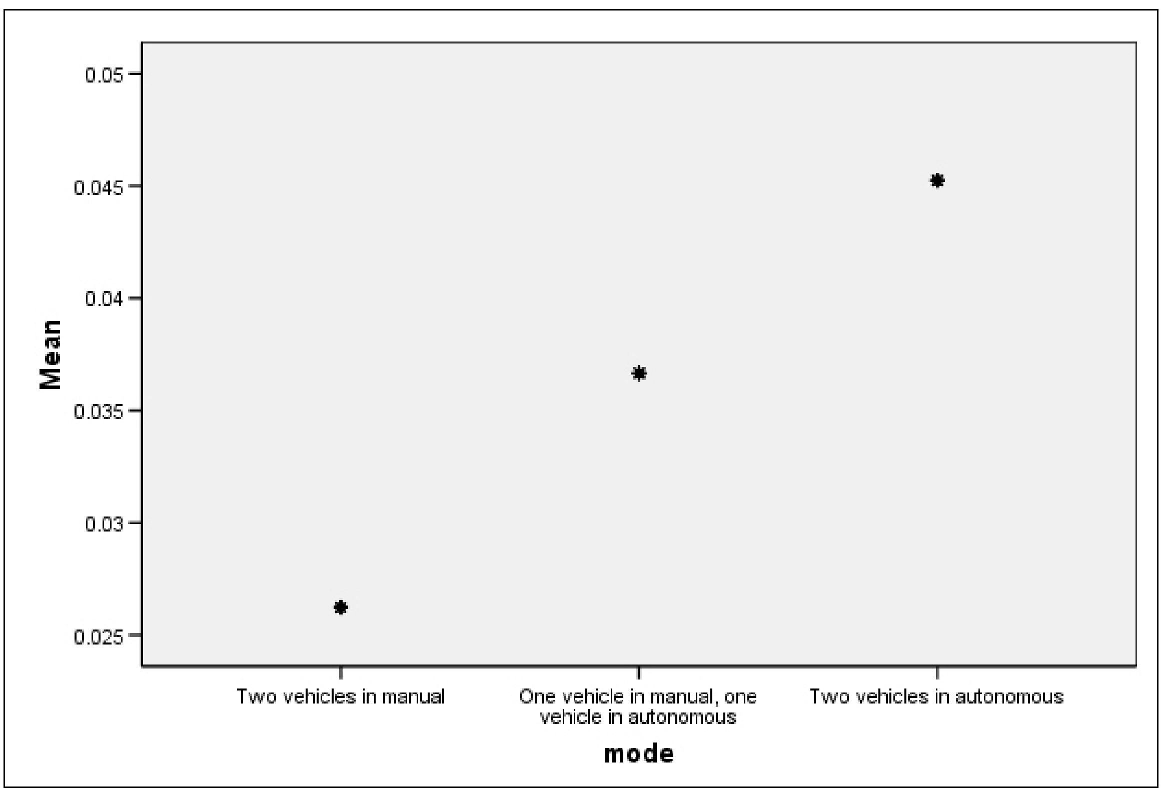

Figure 18. Percent time in overall overload by mode for two vehicles.

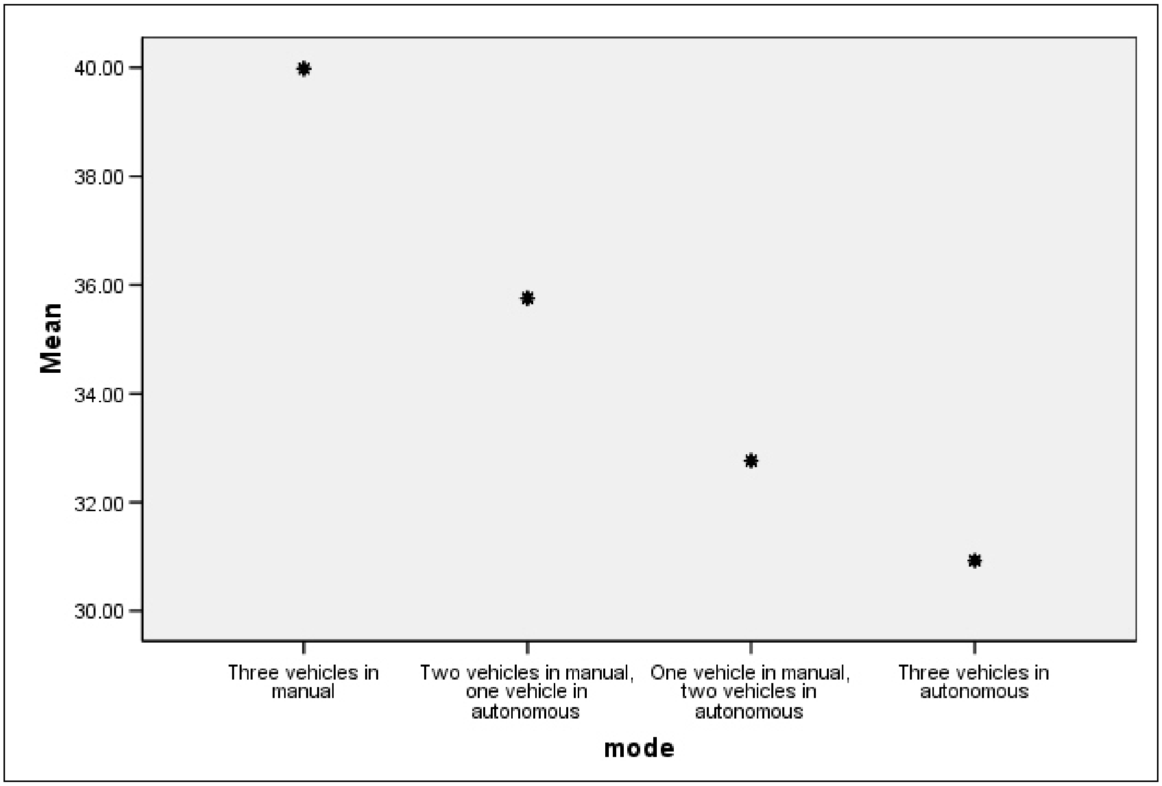

Figure 19. Percent time in visual overload by mode for three vehicles.

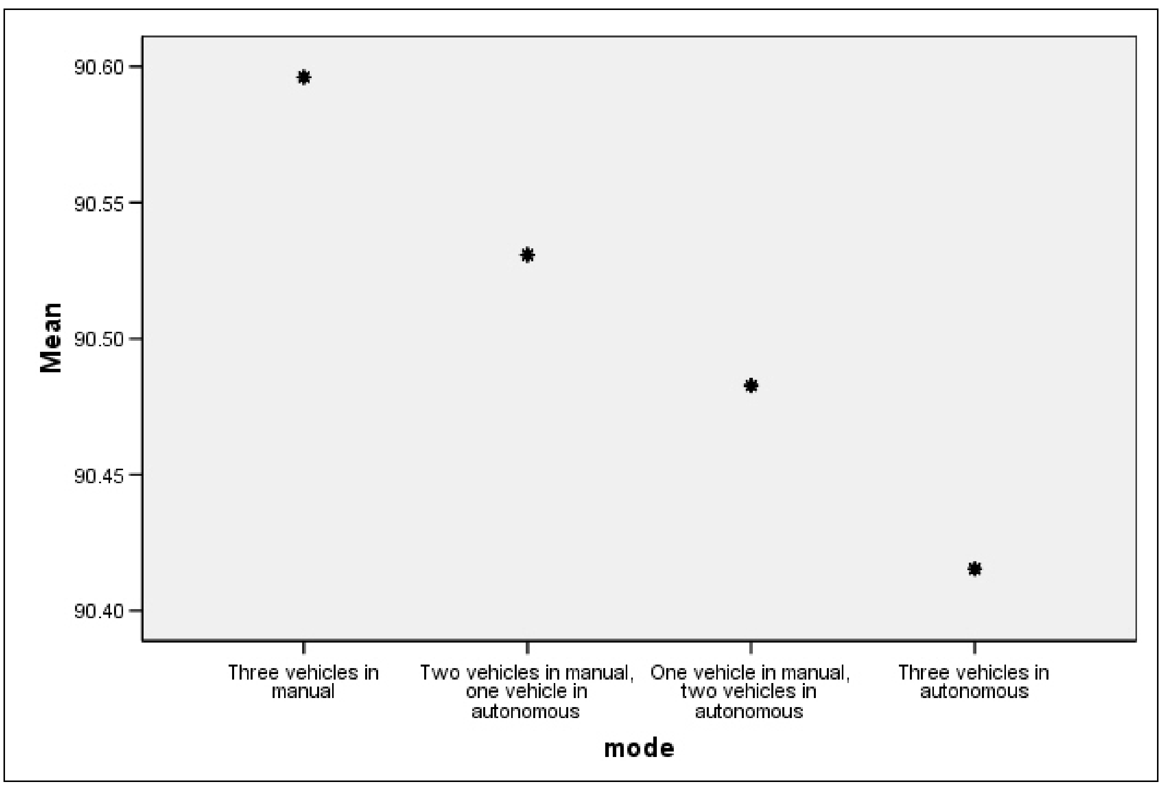

Figure 20. Percent time in cognitive overload by mode for three vehicles.

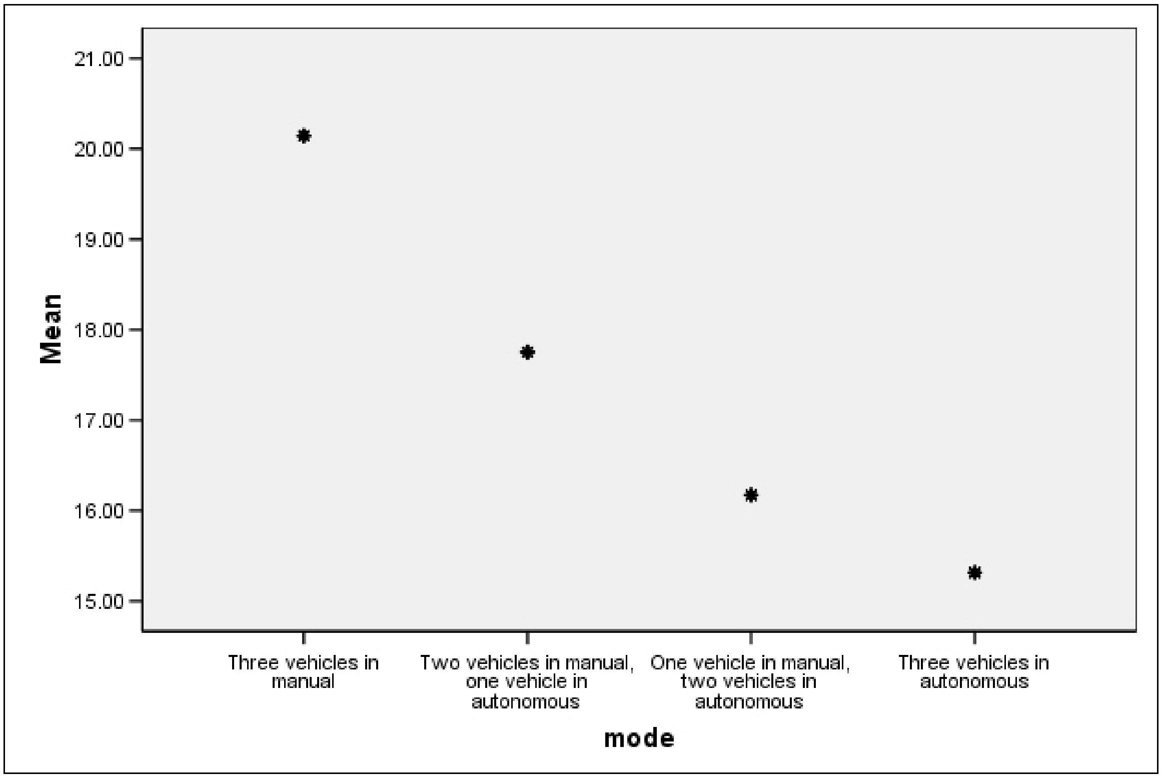

Figure 21. Percent time in overall overload by mode for three vehicles.

4. Discussion

The results from this study indicate that operation of one MAV is well within the mental abilities of the trained Soldier. This is validated by observation of the MAV operators during the training class. This is true, regardless of the mode of operation. Even though the percent time in cognitive overload is significantly different, based on the mode of operation, the level is low (2% to 4%) and would not likely cause any observational or measurable differences in performance errors during these conditions.

Operation of two MAVs may not be within the abilities of a single operator. The overall workload measure indicates that it would be possible. However, examination of the individual channels indicates that regardless of the mode of operation, when a single Soldier operates two vehicles, his or her cognitive workload is above the threshold for the majority of the mission, 80% to 90% of the time. Additionally, the visual channel is overloaded 20% to 40% of the time. It would appear that operation of two MAVs would quickly lead to performance errors and possible mission failure. For both of these channels, manual operation produces a greater demand, significantly greater for the visual channel.

Operation of three MAVs is clearly an overload condition, regardless of the mode of operation. Overall workload measures show that the operator would be in an overload condition for 15% to 25% of the mission. Visual workload would be in an overload condition for 20% to 40% of the mission, and cognitive workload would again be in overload for 90% to 91% of the mission time. For all three measures, manual operation caused a greater demand; however, autonomous operation was still high.

Dixon and Wickens (2003) found that operation of two UAVs was within the capability of a single operator but that performance degraded. In their investigation, dual UAV operation reduced performance in system function monitoring, target of opportunity monitoring, and flight instruction recall. However, tracking performance and target report duration and accuracy were not impacted. They also investigated mitigating techniques of automation and off loading to auditory resource. These techniques helped to mitigate the performance decrements. The mitigation techniques used by Dixon and Wickens support the results of this study. Automation would relieve the cognitive overload, and off loading to auditory relieves the overload to the visual channel.

5. Conclusions

The level of autonomy required to concurrently operate multiple systems effectively is an area that needs further research. This study indicates that for operation of more than one vehicle, a Soldier's workload levels are high enough to predict that performance errors would likely occur. Although errors are predicted, this investigation does not predict what kind of errors would result. Validation studies would help to determine the type of performance error that would likely occur. Validation of the workload numbers and resulting performance impact would be necessary to further this research.

This method can be used to investigate other unmanned platforms. The only requirement is knowledge of the tasks required to operate the system. This method could also be used to predict workload issues and potential performance errors in systems undergoing development.

Additionally, it is important to note that this investigation only looked at tasks required to operate the MAV. Other basic Soldier skills required were not considered and would only increase Soldier workload. Observation during training validates this statement because the Soldiers operating the MAV were so occupied that another Soldier had to carry their weapons for them.

Additional studies would be required to determine specific impact on performance. Also, levels of autonomy would have to be examined to determine what would be the optimum level for operation of multiple UAVs.

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Appendix A. MAV Operator Task List

Table A-1. MAV operator task list.

Function Name	**Task Name**	**Mean Time**
Manual Adjustment 1	Recognize input is required M1	00:00.1
Manual Adjustment 1	Input slow M1	00:00.4
Manual Adjustment 1	Input Medium M1	00:00.4
Manual Adjustment 1	Input Fast M1	00:00.4
Manual Adjustment 1	Input Stop M1	00:00.4
Manual Adjustment 1	Wait for Input Response M1	00:00.1
Monitor Video 1	Monitor Video M1	02:00.0
Monitor Video 1	Change Camera Angle M1	00:00.4
Monitor System Status 1	Monitor System Status M1	00:03.0
Manual Adjustment 2	Recognize input is required M2	00:00.1
Manual Adjustment 2	Input slow M2	00:00.4
Manual Adjustment 2	Input Medium M2	00:00.4
Manual Adjustment 2	Input Fast M2	00:00.4
Manual Adjustment 2	Input Stop M2	00:00.4
Manual Adjustment 2	Wait for Input Response M2	00:00.1
Monitor Video 2	Monitor Video M2	02:00.0
Monitor Video 2	Change Camera Angle M2	00:00.4
Monitor System Status 2	Monitor System Status M2	00:03.0
Manual Adjustment 3	Recognize input is required M3	00:00.1
Manual Adjustment 3	Input slow M3	00:00.4
Manual Adjustment 3	Input Medium M3	00:00.4
Manual Adjustment 3	Input Fast M3	00:00.4
Manual Adjustment 3	Input Stop M3	00:00.4
Manual Adjustment 3	Wait for Input Response M3	00:00.1
Monitor Video 3	Monitor Video M3	02:00.0
Monitor Video 3	Change Camera Angle M3	00:00.4
Monitor System Status 3	Monitor System Status M3	00:03.0
UAV Communication	Press Radio Button	00:00.4
UAV Communication	Speak	00:05.0
UAV Communication	Listen	00:05.0
Receive Vibratory Alert	Receive Vibratory Alert	00:03.0
Receive Vibratory Alert	Acknowledge Vibratory Alert	00:00.1

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Appendix B. Workload Scales

Table B-1. Workload resource scales and verbal descriptors.

Scale Value	Visual Scale Descriptor
0.0	No Visual Activity
1.0	Visually Register/Detect (detect occurrence of image)
3.7	Visually Discriminate (detect visual differences)
4.0	Visually Inspect/Check (discrete inspection/static condition)
5.0	Visually Locate/Align (selective orientation)
5.4	Visually Track/Follow (maintain orientation)
5.9	Visually Read (symbol)
7.0	Visually Scan/Search/Monitor (continuous/serial inspection, multiple conditions)

Scale Value	Auditory Scale Descriptor
0.0	No Auditory Activity
1.0	Detect/Register Sound (detect occurrence of sound)
2.0	Orient to Sound (general orientation/attention)
4.2	Orient to Sound (selective orientation/attention)
4.3	Verify Auditory Feedback (detect occurrence of anticipated sound)
4.9	Interpret Semantic Content (speech)
6.6	Discriminate Sound Characteristics (detect auditory differences)
7.0	Interpret Sound Patterns (pulse rates, etc.)

Scale Value	Cognitive Scale Descriptor
0.0	No Cognitive Activity
1.0	Automatic (simple association)
1.2	Alternative Selection
3.7	Sign/Signal Recognition
4.6	Evaluation/Judgment (consider single aspect)
5.3	Encoding/Decoding, Recall
6.8	Evaluation/Judgment (consider several aspects)
7.0	Estimation, Calculation, Conversion

Scale Value	Psychomotor Scale Descriptor
0.0	No Psychomotor Activity
1.0	Speech
2.2	Discrete Actuation (button, toggle, trigger)
2.6	Continuous Adjustive (flight control, sensor control)
4.6	Manipulative
5.8	Discrete Adjustive (rotary, vertical thumbwheel, lever position)
6.5	Symbolic Production (writing)
7.0	Serial Discrete Manipulation (keyboard entries)

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Appendix C. ANOVA Tables

Table C-1. ANOVA for percent time in visual overload by condition.

	Sum of Squares	df	Mean Square	F	Significance
Intercept	1622239.974	1	1622239.974	276233.1	0.000
Condition	415007.093	8	51875.887	8833.364	0.000
Error	2589.870	441	5.873		
Total	2039836.937	450			

Table C-2. ANOVA for percent time in cognitive overload by condition.

	Sum of Squares	df	Mean Square	F	Significance
Intercept	1748827.760	1	1748827.760	295570.5	0.000
Condition	345665.637	8	43208.205	7302.646	0.000
Error	2609.303	441	5.917		
Total	2097102.701	450			

Table C-3. ANOVA for percent time in overall overload by condition.

	Sum of Squares	df	Mean Square	F	Significance
Intercept	191167.643	1	191167.643	24187.417	0.000
Condition	110051.809	8	13756.476	1740.533	0.000
Error	3485.487	441	7.904		
Total	304704.940	450			

Table C-4. ANOVA for percent time in visual overload by number of vehicles.

	Sum of Squares	df	Mean Square	F	Significance
Intercept	529598.263	1	529598.263	11843.891	0.000
Condition	229276.606	2	114638.303	2563.761	0.000
Error	57995.209	1297	44.715		
Total	102.1834.698	1300			

Table C-5. ANOVA for percent time in cognitive overload by number of vehicles.

	Sum of Squares	df	Mean Square	F	Significance
Intercept	4201932.751	1	4201932.751	369220.7	0.000
Condition	1611628.129	2	805814.065	70806.287	0.000
Error	14760.566	1297	11.381		
Total	1626388.695	1300			

Table C-6. ANOVA for percent time in overall overload by number of vehicles.

	Sum of Squares	df	Mean Square	F	Significance
Intercept	110137.693	1	110137.693	15482.392	0.000
Condition	227784.733	2	113892.366	16010.198	0.000
Error	9226.519	1297	7.114		
Total	338804.611	1300			

Table C-7. ANOVA for percent time in visual overload by mode for one vehicle.

	Sum of Squares	df	Mean Square	F	Significance
Intercept	0.000	1	0.000	5.167	0.024
Condition	2.73E-005	1	2.73E-005	0.761	0.384
Error	0.011	298	3.59E-005		
Total	0.011	300			

Table C-8. ANOVA for percent time in cognitive overload by mode for one vehicle.

	Sum of Squares	df	Mean Square	F	Significance
Intercept	3075.681	1	3075.681	1770.473	0.000
Condition	54.867	1	54.867	31.584	0.000
Error	517.688	298	1.737		
Total	3648.236	300			

Table C-9. ANOVA for percent time in overall overload by mode for one vehicle.

	Sum of Squares	df	Mean Square	F	Significance
Intercept	8.74E-006	1	8.74E-006	1.868	0.173
Condition	8.74E-006	1	8.74E-006	1.868	0.173
Error	0.001	298	4.68E-006		
Total	0.001	300			

Table C-10. ANOVA for percent time in visual overload by mode for two vehicles.

	Sum of Squares	df	Mean Square	F	Significance
Intercept	438154.479	1	438154.479	6647.779	0.000
Condition	7644.560	2	3822.280	57.992	0.000
Error	39348.210	597	65.910		
Total	533072.708	600			

Table C-11. ANOVA for percent time in cognitive overload by mode for two vehicles.

	Sum of Squares	df	Mean Square	F	Significance
Intercept	3793399.340	1	3793399.340	159958.93	0.000
Condition	8.260	2	4.130	0.174	0.840
Error	14157.756	597	23.715		
Total	4229114.346	600			

Table C-12. ANOVA for percent time in overall overload by mode for two vehicles.

	Sum of Squares	df	Mean Square	F	Significance
Intercept	0.702	1	0.702	222.317	0.000
Condition	0.027	2	0.014	4.315	0.014
Error	1.884	597	0.003		
Total	2.698	600			

Table C-13. ANOVA for percent time in visual overload by mode for three vehicles.

	Sum of Squares	df	Mean Square	F	Significance
Intercept	364535.226	1	364535.226	17659.676	0.000
Condition	2828.103	3	942.701	45.669	0.000
Error	8174.326	396	20.642		
Total	488761.980	400			

Table C-14. ANOVA for percent time in cognitive overload by mode for three vehicles.

	Sum of Squares	df	Mean Square	F	Significance
Intercept	2457416.837	1	2457416.837	46329999	0.000
Condition	0.990	3	0.330	6.222	0.000
Error	21.004	396	0.053		
Total	3276596.213	400			

Table C-15. ANOVA for percent time in overall overload by mode for three vehicles.

	Sum of Squares	df	Mean Square	F	Significance
Intercept	90273.999	1	90273.999	14412.040	0.000
Condition	814.074	3	271.358	43.322	0.000
Error	2480.461	396	6.264		
Total	121011.901	400			

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